

METHOD AND SYSTEM FOR HOST PROGRAMMABLE DATA STORAGE DEVICE

SELF-TESTING

Field of the Invention

5 This application relates generally to data storage devices and more particularly to host programmable self-testing of a data storage device.

Background of the Invention

A data storage device such as a magnetic, optical, or magneto-optical drive includes a
10 rotating storage medium. For example, modern disc drives comprise one or more rigid discs that are coated with a magnetizable medium and mounted on the hub of a spindle motor for rotation at a constant high speed. Information is stored on the discs in a plurality of concentric circular tracks typically by an array of transducers ("heads") mounted to a radial actuator for movement of the heads relative to the discs. Each of the concentric tracks is generally divided into a plurality of separately
15 addressable data sectors.

The read/write transducer, e.g. a magnetoresistive read/write head, is used to transfer data between a desired track and an external environment. The heads are mounted via flexures at the ends of a plurality of actuator arms that project radially outward from the actuator body. The actuator body pivots about a shaft mounted to the disc drive housing at a position closely adjacent the outer
20 extreme of the discs. The pivot shaft is parallel with the axis of rotation of the spindle motor and the discs, so that the heads move in a plane parallel with the surfaces of the discs.

The actuator arm is driven by a control signal fed to the voice coil motor (VCM) at the rear end of the actuator arm. A servo system is used to sense the position of the actuator and control the movement of the head above the disc using servo signals read from a disc surface in the disc drive.

The servo system relies on servo information stored on the disc. The signals from this information

5 generally indicate the present position of the head with respect to the disc, i.e., the current track position. The servo system uses the sensed information to maintain head position or determine how to optimally move the head to a new position centered above a desired track. The servo system then delivers a control signal to the VCM to rotate the actuator to position the head over a desired new track or maintain the position over the desired current track.

10 With time, as these components age and wear, problems may develop in the operation of the data storage device. However, field failure analysis of these problems is sometimes difficult. While various types of test can provide accurate analysis of the problems, they typically require the device to be removed from the host for testing. Removal of the device from the host for testing can result in additional problems. For example, removing the device from the host can cause new problems or 15 failures. Additionally, using a different interface for failure analysis may mask some problems and cause other new problems. Finally, some problems may be host specific and testable only while the device is connected to the host.

Accordingly there is a need for a programmable self-test of the data storage device while the device is still connected to the host. The present invention provides a solution to this and other 20 problems, and offers other advantages over the prior art.

Summary of the Invention

Against this backdrop the present invention has been developed. According to one aspect of the present invention, a method of executing one or more self-tests on a data storage device

- 5 comprises selecting one or more host programmable tests stored in memory in the data storage device by setting data in a first log in memory of the data storage device. Parameters for execution of the one or more host programmable tests are set in one or more values in a second log in memory of the data storage device. The one or more host programmable tests on the data storage device are then executed. Results of the one or more host programmable tests are stored in a third log in
- 10 memory of the data storage device.

According to another aspect of the present invention, a data storage device comprises one or more read/write heads, a storage medium accessible by the one or more read/write heads, a processor coupled with the read/write heads to access data on the storage medium, and a memory connected with and readable by the processor. The memory has stored therein one or more host programmable tests overwritten onto vendor specific portions of a self-monitoring program that are executable by the data storage device while the data storage device is connected with a host.

These and various other features as well as advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. 1 is a plan view illustrating the primary internal components of a disc drive incorporating one of the various embodiments of the present invention.

FIG. 2 is a control block diagram for the disc drive shown in FIG. 1 illustrating the primary functional components.

FIG. 3 is a flowchart illustrating data storage device self-testing according to one embodiment of the present invention.

FIG. 4 is a flowchart illustrating a position error signal test that may be part of the self-test illustrated in FIG. 3.

FIG. 5 is a flowchart illustrating a head error rate test that may be part of the self-test illustrated in FIG. 3.

FIG. 6 is a flowchart illustrating a read verify reserve track data test that may be part of the self-test illustrated in FIG. 3.

FIG. 7 is a flowchart illustrating a clear logs test that may be part of the self-test illustrated in FIG. 3.

FIG. 8 is a flowchart illustrating an erase drive test that may be part of the self-test illustrated in FIG. 3.

FIG. 9 is a flowchart illustrating a programmable drive write test that may be part of the self-test illustrated in FIG. 3.

FIG. 10 is a flowchart illustrating executing host programmable tests according to one embodiment of the present invention.

Detailed Description

Embodiments of the present invention will be discussed with reference to a magnetic disc drive. One skilled in the art will recognize that the present invention may also be applied to any data storage device, such as an optical disc drive, a magneto-optical disc drive, or other data storage device having multiple heads for accessing data on multiple storage media.

FIG. 1 is a plan view illustrating the primary internal components of a disc drive incorporating one of the various embodiments of the present invention. The disc drive 100 includes a base 102 to which various components of the disc drive 100 are mounted. A top cover 104, shown partially cut away, cooperates with the base 102 to form an internal, sealed environment for the disc drive in a conventional manner. The components include a spindle motor 106 which rotates one or more discs 108 at a constant high speed. Information is written to and read from tracks on the discs 108 through the use of an actuator assembly 110, which rotates during a seek operation about a bearing shaft assembly 112 positioned adjacent the discs 108. The actuator assembly 110 includes a plurality of actuator arms 114 which extend towards the discs 108, with one or more flexures 116 extending from each of the actuator arms 114. Mounted at the distal end of each of the flexures 116 is a head 118 which includes a fluid bearing slider enabling the head 118 to fly in close proximity above the corresponding surface of the associated disc 108.

During a seek operation, the track position of the heads 118 is controlled through the use of a voice coil motor (VCM) 124, which typically includes a coil 126 attached to the actuator assembly 110, as well as one or more permanent magnets 128 which establish a magnetic field in which the coil 126 is immersed. The controlled application of current to the coil 126 causes magnetic interaction between the permanent magnets 128 and the coil 126 so that the coil 126 moves in

accordance with the well-known Lorentz relationship. As the coil **126** moves, the actuator assembly **110** pivots about the bearing shaft assembly **112**, and the heads **118** are caused to move across the surfaces of the discs **108**.

The spindle motor **106** is typically de-energized when the disc drive **100** is not in use for 5 extended periods of time. The heads **118** are moved away from portions of the disk **108** containing data when the drive motor is de-energized. The heads **118** are secured over portions of the disk not containing data through the use of an actuator latch arrangement and/or ramp, which prevents inadvertent rotation of the actuator assembly **110** when the drive discs **108** are not spinning.

A flex assembly **130** provides the requisite electrical connection paths for the actuator 10 assembly **110** while allowing pivotal movement of the actuator assembly **110** during operation. The flex assembly includes a printed circuit board **134** to which a flex cable leading to the head is connected; the flex cable leading to the heads **118** being routed along the actuator arms **114** and the flexures **116** to the heads **118**. The printed circuit board **132** typically includes circuitry for controlling the write currents applied to the heads **118** during a write operation and a preamplifier for 15 amplifying read signals generated by the heads **118** during a read operation. The flex assembly terminates at a flex bracket **134** for communication through the base deck **102** to a disc drive printed circuit board (not shown) mounted to the bottom side of the disc drive **100**.

FIG. 2 is a control block diagram for a disc drive illustrating the primary functional 20 components of a disc drive incorporating one of the various embodiments of the present invention and generally showing the main functional circuits which are resident on the disc drive printed circuit board and used to control the operation of the disc drive **100**. The disc drive **100** is operably connected to a host computer **140** in a conventional manner. Control communication paths are

provided between the host computer 140 and a disc drive microprocessor 142, the microprocessor 142 generally providing top level communication and control for the disc drive 100 in conjunction with programming for the microprocessor 142 stored in microprocessor memory (MEM) 143. The MEM 143 can include random access memory (RAM), read only memory (ROM) and other sources 5 of resident memory for the microprocessor 142.

The discs 108 are rotated at a constant high speed by a spindle motor control circuit 148, which typically electrically commutes the spindle motor 106 (FIG. 1) through the use, typically, of back electromotive force (BEMF) sensing. During a seek operation, wherein the actuator 110 moves the heads 118 between tracks, the position of the heads 118 is controlled through the application of 10 current to the coil 126 of the voice coil motor 124. A servo control circuit 150 provides such control. During a seek operation the microprocessor 142 receives information regarding the velocity of the head 118, and uses that information in conjunction with a velocity profile stored in memory 143 to communicate with the servo control circuit 150, which will apply a controlled amount of current to the voice coil motor coil 126, thereby causing the actuator assembly 110 to be pivoted.

15 Data is transferred between a host computer 140 or other device and the disc drive 100 by way of an interface 144, which typically includes a buffer to facilitate high speed data transfer between the host computer 140 or other device and the disc drive 100. Data to be written to the disc drive 100 is thus passed from the host computer 140 to the interface 144 and then to a read/write channel 146, which encodes and serializes the data and provides the requisite write current signals to 20 the heads 118. To retrieve data that has been previously stored in the data storage device 100, read signals are generated by the heads 118 and provided to the read/write channel 146, which performs

decoding and error detection and correction operations and outputs the retrieved data to the interface 144 for subsequent transfer to the host computer 140 or other device.

Stored in memory 143 may be a self-monitoring program such as the Self-Monitoring, Analysis, and Reporting Technology (SMART) feature set. This, and similar programs, monitor a 5 variety of parameters of the data storage device during normal operation. These programs contain a number of vendor specific extensions or tests that are not typically used after manufacture of the device. Additionally, these self-monitoring programs utilize a number of easily accessible memory locations or logs that may be used to store information. Generally, embodiments of the present invention utilize the vendor specific portions of these self-monitoring programs and logs to provide 10 host programmable self-test.

FIG. 3 is a flowchart illustrating data storage device self-testing according to one embodiment of the present invention. Here, processing begins with determination operation 305. Determination operation 305 comprises selecting and programming boundary parameters of one or more host programmable tests provided with the data storage device. That is, the supplier of the data 15 storage device determines which host programmable tests will be made available on the device to be executable by the data storage device while the data storage device is connected with a host. When executed, the user, via the host with which the data storage device is connected, can select one or more of the test to be executed as well as setting parameters for the execution of those tests. In one example, the type of test to be performed may be indicated by the user setting data in a log in the 20 memory of the data storage device. Additionally, setting parameters for execution of the one or more host programmable tests may be done by the user setting one or more values in a second log in memory of the data storage device.

Examples of these tests will be discussed below with reference to FIGs. 4-9. Host programmable tests that may be available include, but are not limited to, a Position Error Signal (PES) test, a head error rate test, a read verify reserve track data test, and others as will be discussed below. Control then passes to query operation 310.

5 Query operation 310 comprises determining the mode of operation the selected tests shall be executed in. In some devices, tests may be executed in two modes of operation, such as offline and captive. If at query operation 310 a determination is made that the test mode is captive mode, control passes to execute operation 320.

10 Execute operation 320 comprises executing the selected tests in a captive mode. In captive mode, tests are executed while host-initiated commands are ignored until the data storage device has completed all selected tests. Control then passes to log operation 330.

15 If, at query operation 320, a determination is made that the test mode is not captive mode, control passes to execute operation 325. Execute operation 325 comprises executing the selected tests in an offline mode. In offline mode tests can be executed and data collected when the data storage device is not servicing host-initiated commands. Control then passes to log operation 330.

20 Log operation 330 comprises writing the data collected during execution of the selected tests to the appropriate vendor specific logs. For example, the self-monitoring program stored in memory in the data storage device may be the Self-Monitoring, Analysis, and Reporting Technology (SMART) program or another similar program. SMART provides a number of vendor specific tests that are not used after manufacture of the device as well as a number of logs stored in the memory of the device. The host programmable tests may be overwritten on these vendor specific tests.

Additionally, as will be seen below, the logs may be used to store control information and results for the host programmable tests.

FIG. 4 is a flowchart illustrating a Position Error Signal (PES) test that may be part of the self-test illustrated in FIG. 3. In this example, processing begins with select operation **405**. Select 5 operation **405** comprises selecting a read/write head of the data storage device and a track of a storage medium in the data storage device to be tested where the selected track is accessible by the selected read/write head. Control then passes to receive operation **410**.

Receive operation **410** comprises receiving a host request for servo data from the selected track. That is, through the host, a tester may request one or more servo sectors of the storage 10 medium to be read and tested. Control then passes to read operation **415**.

Read operation **415** comprises collecting PES data from the selected track while reading the requested servo data. In some cases, the PES data may be calculated as a percentage off-track value for the head and track being tested. Control then passes to store operation **420**.

Store operation **420** comprises storing the collected PES data in a log in memory of the data 15 storage device. That is, the collected PES data may be stored in a log such as the SMART logs where it can be accessed via the host or another means.

FIG. 5 is a flowchart illustrating a head error rate test that may be part of the self-test illustrated in FIG. 3. Processing begins with select operation **505**. Select operation **505** comprises selecting a range of addresses to be tested on a storage medium in the data storage device. For 20 example, a starting and ending address, such as a Logical Block Address (LBA), may be specified. In some cases, these addresses may be set by the tester in logs, such as SMART logs, in the memory of the data storage device. Control then passes to read operation **510**.

Read operation **510** comprises collecting head error rate data for the range of addresses selected. That is, as data is read from the storage medium between the starting and ending addresses, error rate information is collected. Control then passes to store operation **515**.

Store operation **515** comprises storing the head error rate data and a test complete status in a log in memory of the data storage device. That is, the collected error rate data may be stored in a log such as the SMART logs where it can be accessed via the host or another means.

FIG. 6 is a flowchart illustrating a read verify reserve track data test that may be part of the self-test illustrated in FIG. 3. Here, processing begins with read operation **605**. Read operation **605** comprises performing a sector-by-sector read of reserve track data on a storage medium of the data storage device. Control then passes to query operation **610**.

Query operation **610** comprises determining whether an uncorrectable error has been detected during the sector-by-sector read of the reserve track data on the storage medium. If a determination is made that no uncorrectable errors have been detected, control passes to store operation **615**. If, however, a determination is made that one or more uncorrectable errors have been detected, control passes to store operation **620**. Store operation **620** comprises storing a number of errors and an offset value for each error. That is, the collected error data may be stored in a log such as the SMART logs where it can be accessed via the host or another means. Control passes to store operation **615**.

Store operation **615** comprises storing a test complete signal in a log in memory of the data storage device. That is, the test complete signal may be stored in a log such as the SMART logs where it can be accessed via the host or another means.

FIG. 7 is a flowchart illustrating a clear logs test that may be part of the self-test illustrated in FIG. 3. In this example, processing begins with query operation **705**. Query operation **705** comprises determining whether a test key stored in a first log of a plurality of logs in memory of the data storage device has been set. That is, since this function is destructive of information in the logs, 5 a key is used to verify the intention to perform this function. The key may be in the form of a flag or other information such as a password stored in the logs by the tester. If, at query operation **705**, a determination is made that the test key has not been set, no further processing is performed. If, however, a determination is made that the test key has been properly set, control passes to set operation **710**.

10 Set operation **710** comprises clearing all logs of the plurality of logs in memory of the data storage device. That is, all logs in the data storage device memory, such as SMART logs, are cleared. Control then passes to erase operation **715**.

Erase operation **715** comprises erasing the test key. Once again, since the clear logs function is destructive, the key will be erased after use to prevent accidental re-execution of the function.

15 FIG. 8 is a flowchart illustrating an erase drive test that may be part of the self-test illustrated in FIG. 3. Processing begins with query operation **805**. Query operation **805** comprises determining whether a test key stored in a first log in memory of the data storage device has been set. That is, since this function is destructive of information on the storage medium, a key is used to verify the intention to perform this function. The key may be in the form of a flag or other information such as 20 a password stored in the logs by the tester. If, at query operation **805**, a determination is made that the test key has not been set, no further processing is performed. If, however, a determination is made that the test key has been properly set, control passes to query operation **810**.

Query operation **810** comprises determining whether an erase start address and an erase end address stored in a second log in memory of the data storage device are within a range of addresses available on the data storage device. That is, an erase start address and an erase end address, perhaps in the form of an LBA, may be stored in the logs in the memory of the data storage device. These 5 addresses are checked to determine whether they are valid addresses for the data storage device. If the erase start address and the erase end address stored in the second log in memory of the data storage device are not within a range of addresses available on the data storage device, no further processing is performed. However, if the start and end addresses are within the range of available addresses, control passes to erase operation **815**.

10 Erase operation **815** comprises erasing the storage medium of the data storage device in the range specified by the erase start and erase end addresses. Control then passes to erase operation **820**.

Erase operation **820** comprises erasing the test key. Once again, since the erase function is destructive, the key will be erased after use to prevent accidental re-execution of the function.

15 FIG. 9 is a flowchart illustrating a programmable rewrite test that may be part of the self-test illustrated in FIG. 3. Here, processing begins with query operation **905**. Query operation **905** comprises determining whether a test key stored in a first log in memory of the data storage device has been set. That is, since this function is destructive of information on the storage medium, a key 20 is used to verify the intention to perform this function. The key may be in the form of a flag or other information such as a password stored in the logs by the tester. If, at query operation **905**, a determination is made that the test key has not been set, no further processing is performed. If,

however, a determination is made that the test key has been properly set, control passes to query operation **910**.

Query operation **910** comprises determining whether a rewrite start address and a rewrite end address stored in a second log in memory of the data storage device are within a range of addresses 5 available on the data storage device. That is, a rewrite start address and a rewrite end address, perhaps in the form of an LBA, may be stored in the logs in the memory of the data storage device. These addresses are checked to determine whether they are valid addresses for the data storage device. If the erase start address and the erase end address stored in a log in memory of the data storage device are not within a range of addresses available on the data storage device, no further 10 processing is performed. However, if the start and end addresses are within the range of available addresses, control passes to rewrite operation **915**.

Rewrite operation **915** comprises rewriting data on a storage medium of the data storage device with a value stored in a third log in memory of the data storage device in the range specified by the rewrite start and rewrite end addresses. That is, the tester may set a rewrite pattern in the logs 15 in memory of the data storage device. This pattern will then be rewritten to all data located between the starting and ending addresses. Control then passes to erase operation **920**.

Erase operation **920** comprises erasing the test key. Once again, since the rewrite function is destructive, the key will be erased after use to prevent accidental re-execution of the function.

FIG. 10 is a flowchart illustrating executing host programmable tests according to one 20 embodiment of the present invention. Here, processing begins with select operation **1005**. Select operation **1005** comprises selecting one or more host programmable tests stored in memory in the data storage device by setting data in a first log in memory of the data storage device. That is, the

tester may select one or more of the host programmable tests but setting a flag or other data in a specific log in the memory. Control then passes to set operation **1010**.

Set operation **1010** comprises setting parameters for execution of the one or more host programmable tests by setting one or more values in a second log in memory of the data storage device. In other words, the tester sets parameters such as a test key, starting address, ending address, and other parameters discussed above in the logs. Control then passes to execute operation **1015**.

Execute operation **1015** comprises executing the one or more host programmable tests on the data storage device. Control then passes to read operation **1020**.

Read operation **1020** comprises retrieving results of the one or more host programmable tests from a third log in memory of the data storage device. That is, the tester, through the host or by another means, reads the test results saved in the logs as indicated above.

It will be clear that the present invention is well adapted to attain the ends and advantages mentioned as well as those inherent therein. While a presently preferred embodiment has been described for purposes of this disclosure, various changes and modifications may be made which are well within the scope of the present invention. For example, a self-monitoring program other than SMART may be used to provide host programmable tests. Additionally, more, fewer, or different tests than those discussed herein may be made available as host programmable tests. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.